OPERATING CONDITIONS AND TYPES OF WIND-POWER ELECTRIC SUBSTATIONS FOR RURAL AREAS.

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REGIMES OF WORK AND TYPES OF WIND-DRIVEN ELECTRIC POWER INSTALLATIONS FOR RURAL REGIONS

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ABSTRACT

The efficiency of regimes of work of wind-motor electric generating sets, working in a system jointly with other power stations, with constant and variable speed of rotation of the windmill, is compared. A method is given for evaluating the possible percentage of participation of wind-driven installations in the power supply of rural regions, based on the future power balances of the regions and the technical conditions for the operation of wind-driven installations. /33*

Recently new technical possibilities have been discovered for the use of wind-motor electric generating sets in joint work with other power stations in one electrical system. Soviet priority for a wind-motor electric generating set, working parallel with a high-power system, was established in 1931 with the construction of an experimental installation in the Crimea, which worked with an asynchronous generator and yielded into the total network up to 120 kW. Ten years later, in 1941, a unit was built in the U.S.A. which worked on a similar scheme with a synchronous generator, combined with a windmill with the aid of a hydraulic clutch. The latter, in view of its difficulty of operation for a small installation, makes such a system unpromising for broad distribution.

*Numbers in the margin indicate pagination in the foreign text.

Comparison of regimes of work of a wind-driven electric power station with constant and variable angular velocity of the windmill. Along with constant adoption of the work of a windmill in a regime with constant angular velocity, which is usual for steam and water turbines and other primary engines used in power stations, in wind-driven technology there is also another tendency--to adapt the scheme for generation of electrical energy to the optimal aerodynamic regime of the windmill, which is a regime with variable speed of rotation and a constant modulus of speed. This regime requires, however, for maintaining a constant frequency, in principle, a new and more complex type of generator or complex system of transmission from the engine to the generator.

The author undertook an attempt to compare the efficiency of these two regimes in regard to power.

In the work of a windmill with constant angular velocity (the first regime) the high-speed modulus of the engine $z = \frac{\omega R}{v}$, representing the ratio of the circular velocity of the end of the blade ωR to the speed of the wind v, increases at low wind speeds, while the utilization factor of the energy of the wind decreases (Fig. 1, first part of the curves), and, therefore, low wind speeds are used with poor ξ.

With variable angular velocity (second regime) and a corresponding ideal selection of the characteristic of the generator (Fig. 2), the engine can work in a constant modulus z and a maximum ξ at all working speeds of the wind, as a result of which in work in a system with high power, an increase in annual generation is obtained.

For engines with rotating blades, there is also possible an improved regime of work for a constant number of revolutions with a variable initial adjustment of the aerodynamic setting, corresponding to a change in the angle of the sails toward the relative current of the wind. This regime requires automatic changing of this angle depending on the speed of the wind. With engines which regulate by means of stabilizers, it is characterized by a change in the quantity a of the adjustment of the aerodynamic setting of the sails (corresponding to a change in the angle between the chords of the transverse sections of the blade and the stabilizer. With this regime (Fig. 1, curve for the D-30 with a variable) low wind speeds are used with higher ξ than with the first basic regime.

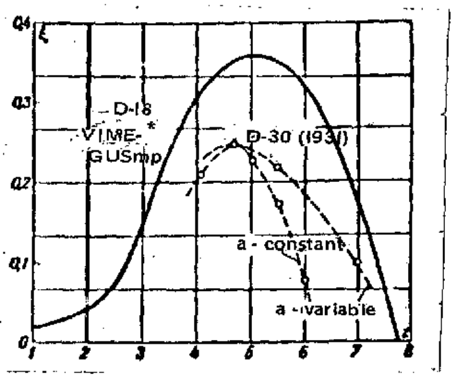

Fig. 1. Curves for windmills. a-- amount characterizing the adjustment of an aerodynamic setting of the windmill.
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A series of schemes are known which produce the second regime of work of the system, such as: a scheme with an engine working with a synchronous generator through an intermediate hydraulic drive, consisting of a pump and a hydroturbine; schemes for frequency transformation, consisting of several electrical machines, schemes with generation of direct current and its transformation into alternating current, etc. All of these are relatively complex, especially for low-power installations, and they are characterized by significantly lower efficiency than a /34 scheme with a synchronous generator directly connected with a windmill. The decrease in efficiency, which is evident with all loads, can lower or even completely reduce the effect obtained with this regime from improving ξ of the engine at low wind speeds.

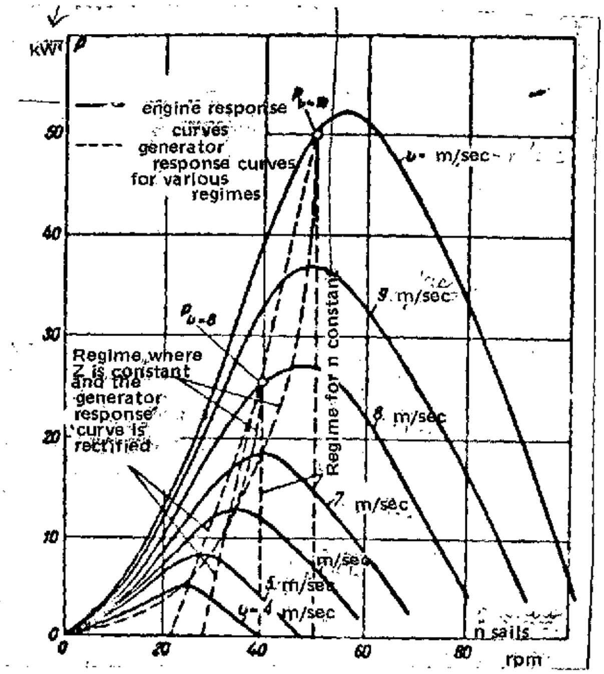

Fig. 2. Curves of the D-18 system with various regimes of work. $R_v = 10$ and $R_v = 8$-- adjusted capacities of the system with corresponding calculations of v.

The number of hours per year at low wind speeds and the corresponding percentage of the annual generation of the wind-motor electric generating sets by the wind, by virtue of the existing laws for the annual distribution of these speeds, depends on the amount of average annual wind speed, increasing when it decreases. As a result of this, the increase in generation possible in the second or the improved first regimes of work of wind-motor electric generating sets will depend on the wind conditions.

of the region in which the installation is working, i.e., on the amount of the average annual norm[1] of wind speed v_{av}.

A comparison of the regime of work of wind-motor electric generating sets in power generation was made for a range of average wind speeds from 4 to 8 m/sec over a period of years, which embraces the greater part of wind conditions encountered in practice. For all calculations, the author adopted the following conditions:

1. Calculated responses of the high-speed wind engine D-18 VIME-GUSMP, with regulation of the rotation of the end of the blade with the help of a stabilizer. This engine, produced recently in an experimental series, is at present the most suitable of the existing ones in type and power for electrification of agricultural regions. The results of the calculations made on the basis of its characteristics are applicable both to engines of the same type with a different diameter of the sails and to other types of engines which have similar aerodynamic characteristics of the sails.

2. The calculated wind speeds, corresponding power of the system set-up, and the number of rotations of the sails per minute are optimal for the given wind speed v for maximum annual generation. The optimal number of revolutions per minute is limited by the extreme surrounding speed at the ends of the blades, adopted as 45 m/sec.

3. The r. m. s. value η_2 for the second regime of work was given in three variations: a) η_2 is equal to the corresponding efficiency of a synchronous generator ($\eta_2 = \eta_s$); b) η_2 is lower than it by 0.05; c) η_2 is lower by 0.10. It was accepted

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[1]The average velocity v_{av} at the height of the center of a wind wheel of 20-30 m under conditions of plain terrain will be 20-30% greater than according to the data of the meteorological network.

conditionally that the relationship of η_2 to the load is the same as for η_s.

4. The distribution of wind speeds is according to Gullen-Yemtsov.

The results of the calculations are given in the form of curves in Fig. 3. The increase in generation was taken in regard to the first regime. According to the curves, it is evident that greater effectiveness from use of low wind speeds may be obtained in regions with low average annual wind speeds. In work with a variable speed of revolution in a constant module and $\eta_1 = \eta_0$ (curve 1), the maximum increase in generation in a range of average speeds v_{av} from 4 to 8 m/sec may constitute from 3% to 25%. In regions with average wind speeds $v_{av} = 5.5$-6 m/sec, in which wind-motor electric generating sets may be more widespread, the increase in generation may amount to up to 10%. When η_2 is lowered by 0.05, an increase in generation is possible only when $v_{av} = 5.5$ m/sec, and at high average wind speeds it is completely compensated for by a decrease in η_2. When η_2 is decreased by 0.10, a small increase in generation will take place only in regions with low wind speeds in the order of $v_{av} = 4$ m/sec, where wind-motor electric generating sets will be built very rarely.

In case of the use of windmills with other types of sails /35 which differ from those adopted by us as normal, the effect of increase in generation in the second regime of work of the wind-motor electric generating sets will also depend on the aerodynamic efficiency and form of the aerodynamic curve of the sails. The worse the quality of the sails and the steeper the fall in the curve in the right part at large modules (Fig. 1), corresponding to work at constant speed of rotation at low wind speeds, the more favorable is the work with variable speed and constant $\xi = \xi_{max}$. For example, for sails of the old type of the D-30 system

(1931), which have ξ_{max} = 0.24 with a steep curve (L. 2), the curve 6 of increase in generation with a variable number of revolutions will lie significantly higher than curve 1 for the D-18 system with normal parameters of the sails.

In a case where the use of a synchronous generator makes it necessary to change the normal aerodynamic characteristics of a windmill, which has a possible influence on the amount of the annual generation of a wind-motor electric generating set towards reducing it somewhat, the limits of suitability of the use of the second regime of work are somewhat expanded, but nevertheless in the range of comparatively high average wind speeds which interests us, taking into account the necessary reduction of η, its characteristics will not be optimal.

In order to determine the increase in generation with an improved first regime of work, corresponding experimental characteristics of the D-18 engine are required, which so far are lacking. Curve 5 is constructed for this regime approximately on the basis of comparison with curves 6 and 7, which relate to the D-30 engine of the previous design. The increase in generation in this regime when v'_{av} = 5 m/sec can be only about 5%, but when it is possible to use an uncomplicated device for automatically changing the initial adjustment of the aerodynamic setting of the engine, the use of this regime for engines with revolving blades may be expedient, despite the small amount of increase in generation obtained.

The profitability of the use of one or another of the regimes of work of wind-driven electric stations discussed is determined in the final analysis by economic calculation, considering both the amount of generation of electrical energy with a concrete value of η_2 and the degree of reliability of the equipment in operation and its cost.

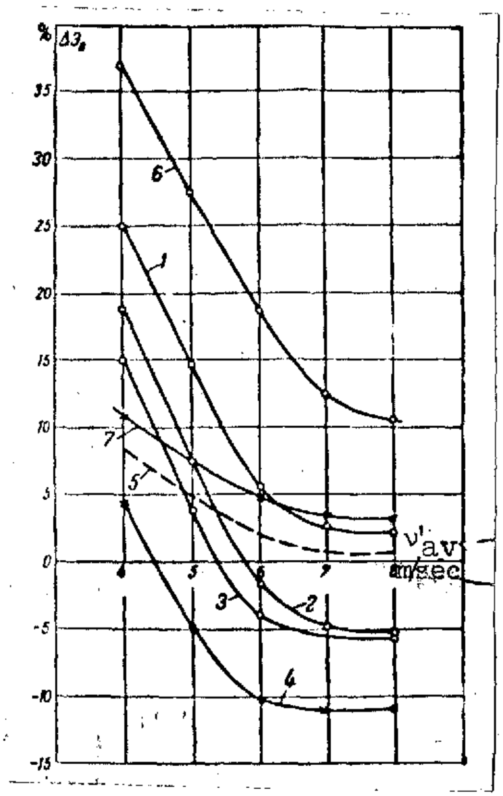

Fig. 3. Curves of increase in generation, depending on the average annual wind velocity (in regard to the regime of the D-18 unit when n and a are constant).
D-18 (ξ = 0.36): 1--n is variable, z is constant, $\eta_2=\eta_s$; 2--n is variable; rectified response, $\eta_2=\eta_s$; 3--n is variable, z is constant, $\eta_2=\eta_s$ - 5%; 4--n is variable, z is constant, $\eta_2=\eta_s$ - 11%; 5--n is constant, a is variable (in comparison to curves 7, D-30 (ξ=0.24); 6-- n is variable, z is constant, $\eta_2=\eta_s$; 7-- n is constant, a is variable.

The use of a special generator for work with a windmill with variable speed of rotation may become very suitable if it will be possible to use it with a windmill of a simplified type, with firmly attached blades without aerodynamic regulation, which would not be overloaded at high wind speeds. One of the possible designs for such a generator is conceived as closely related to the collector generator working with frequency transformation, proposed by Prof. M. P. Kostenko for work with a hydroturbine [3]. The use of these resources may lead to significant reduction in weight, simplification, and reduction in cost of the engine, the weight and cost of which has decisive significance for the economy of the entire system as a whole. It is possible that it will be expedient to expand the range of speeds of rotation of such a generator, due to low wind speeds.

The participation of wind-driven installations in the electrical supply of agricultural regions. The second task of this article is an attempt to evaluate the prospects for the percentage of participation of wind-powered installations in the energy supply of agricultural regions.

The calculation of potential energy resources of the wind from 1 km^2 of territory, determined for average wind speeds, yields enormous amounts. For example, when $v_{av} = 5$ m/sec, the average annual power from 1 km^2 is obtained as equal to about 120 kW against the energy volume of agriculture measured in kilowatt units. By virtue of the specific characteristics of wind energy, consisting of its dispersion and inconstancy, the potential resources of the wind do not correspond at all to the real possibilities for their use.

In evaluating the real amounts of possible use of wind energy in agriculture, besides the basic features of wind energy indicated, limiting the possibilities for its use, it is necessary also to take into account the following factors: 1) the amount of the energy volume of the technological consumption of the regions; 2) the use of other types of local energy resources for offsetting the load and also of regional systems; 3) the degree of coincidence of load graphs with the graphs of output of wind-driven installations by the wind; 4) the economic profitability of the parallel use of wind-motor electric generating set with other electric stations depending on wind conditions of the given region; 5) the technical level of development of wind-motor electric generating sets and the conditions for their parallel work with other stations. /36

Consequently, the percentage of possible participation of wind-powered installations in the energy supply of agricultural regions may be evaluated by composing prospective energy balances in which, in the first place, the use of local resources of hydroenergy of small rivers and local fuel must be stipulated. The use of fuel transported over a long distance, especially of oil products, for burning in local power installations, is inadmissible from the point of view of expediency for the national economy. The use of wind energy as an additional power source of local energy must be developed in those regions which are deficient in local energy resources, which possess sufficiently high wind speeds, in the order of $v_{av} = 4.5$-5 m/sec (according to the data of the meteorological network).

As is known, due to unevenness of output of wind-motor electric generating sets over time, their offsetting the load schedule in parallel work with other electrical stations is possible only in kilowatt hours. In regard to installed capacity, they must be duplicated by other electric stations. For this same reason, completely efficient use of wind-driven installations is possible only in a case where the hours of their work by the wind coincide with the load schedule, and the total installed capacity of the wind-motor electric generating set does not exceed the minimum 24-hour load schedule, which, for an agricultural energy system with some regulation of load, may be taken as 25% of the maximum.

The economic profitability of wind-motor electric generating consists in a reduction in total operational expenditures in the energy system, caused by a saving of fuel, a reduction in the radiuses of its delivery with a decrease in demand for it and from a possible increase in installed capacity and an increase in the use of parallel-working regulating hydrostations [1]. The presence of hydroelectric stations may in some cases increase the use of the current of water by several times.

The cost of wind energy in regions with average wind speed on the order of 4.5 m/sec, without considering the reduction in energy cost of other stations with the work of wind-motor electric generating sets, will be less than the energy obtained from local thermal stations.

The use of wind-motor electric generating sets at the present time was tested with an asynchronous generator in parallel work with a high-power system. In the work of wind-motor electric generating sets with a local system of equal power, the question arises of the quality of the energy obtained corresponding to the norms of allowable deviation of frequency from the nominal in oscillations of output of wind-motor electric generating sets. According to preliminary calculations of the VIESKh,* based on conditions allowable in rural systems of frequency oscillations of 10%, wind-motor electric generating sets, working in parallel with the local system, may cover up to 30% of the active load of the network with the work of thermal engines and hydroturbines without regulators of revolutions, and from 50-100% when there are regulators, depending on the quality of the regulators and the inertial constant system [4].

The question of the stability of the work of wind-motor electric generating set with the use of synchronous generators is in the stage of study. But at present, based on a simple electrical scheme of wind-motor electric generating sets with an asynchrous generator, we can accept, with verification in the future by experiment, the admissible ratio of installed capacities of wind-motor electric generating sets and the local system for some kind of average amount within the above-indicated limits, i.e., on the order of 0.25. Such an amount of installed capacity of wind-motor electric generating sets was adopted with the supposition that 25% of the other primary engines working in the system have a sufficiently small amount of inertial constant and high-quality

*All-Union Scientific Research Institute of Rural Electrification regulators of revolutions, while 75% of the engines work without regulators, which under the conditions of rural electrical stations is actual. The ratio adopted, furthermore, ensures 100% of the use of the energy of wind-motor electric generating sets when the schedule of their output by wind coincides with the load schedule.

The participation of wind-motor electric generating sets covering the load according to energy with an average number of hours of use of $T_{weg} = 1{,}800$ and $T_{sys} = 2{,}800$ is expressed as

$$(Elec_{weg}/Elec_{sys}) \cdot 100\% = \frac{0.25.1800.100\%}{2800} = 16\%.$$

With power of the local systems of from 100 to 1,000 kW, the wind-motor electric generating sets can be based on systems with existing diameters of wind wheels D-18 and D-30, with an installed capacity according to generators, depending on v_{av}, of from 30 to 150 kW.

For increasing the share of participation of wind energy in covering of the load, several production processes of agriculture, which permit work according to a flexible schedule (such as milling of grain, feed preparation, spraying, etc.) which can constitute a total of about 15% of the stationary use, may be expediently transferred to work by wind-driven installations with mechanical drive, using for this purpose D-12 and D-18 engines with 10-30 kW of power.

Networks fed from powerful regional stations, both existing ones and those which are to be built, from which the remaining agricultural load not covered by local energy systems must be fed, also must be joined in regions with favorable wind conditions to a certain number of large wind-motor electric generating sets with a diameter of the sails on the order of the D-50 and an installed capacity of 700-1,000 kW. The total power from these wind-motor electric generating sets may be taken as equal to up to 30% of the maximum agricultural part of the load, based on the amount of the annual minimum of the load schedule of 50% by deducing the power of electric stations working according to an obligatory schedule. The percentage of participation of wind-motor electric generating sets in covering the load schedule according to energy analogous to the previous calculation will in this case amount to about 20%.

In certain regions with strongly developed local systems, the participation of the wind-motor electric generating sets in the local systems in regard to the absolute amount of output will be significant, but, in an average system, in regard to total energy consumption, it will be small. Thus the total participation of wind-powered stations of all types, including those with mechanical drive, in covering the demand for agricultural regions, may constitute, on the average, about 1/3 of the total of the stationary consumption.

Of all the electrical energy produced by wind-motor electric generating sets, 80% should be obtained from wind-motor electric generating sets joined to powerful regional networks, which constitutes 50% of the entire energy which can be obtained from wind-driven installations.

Conclusions. 1. The regime of work of wind-motor electric generating sets with variable speed of rotation and a constant modulus of the windmill does not have substantial advantages for increasing the energy output on account of better use of low wind speeds before the regime with constant speed of rotation.

2. Research work on the use of special types of generators for work with a windmill with variable speed of rotation must be connected with the possibility of using for wind-motor electric generating sets cheap windmills with firmly attached blades without

any setting, thus making improvement in the use of low wind speeds merely a side task.

3. An evaluation of the possible future percentage of participation of wind-powered units in covering the loads of agricultural regions may be done on the basis of study of the power consumption demand and local energy resources taking into account the technical possibilities for the use of wind-driven devices.

4. Wind-driven units must find use in those agricultural regions of the U.S.S.R. where there are favorable wind conditions and a deficiency in other local energy resources, working as wind-motor electric generating sets in regional and local systems, and also in the form of small- and medium-sized devices with mechanical drive.

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